IN THE SPECIFICATION:

Please amend the specification as follows:

[0004] However, in the conventional ball endmill, since the radius of curvature of each ball-nosed end cutting edge is constant from the inner peripheral portion to the outer peripheral portion, a cutting resistance (cutting torque) is exerted by a workpiece and ~~radially~~ acts on the ball endmill in a direction that is concentrated to be substantially constant, and consequently causing the ball endmill to be vibrated. Due to such a problem, the feed rate and the depth of cut can not be increased whereby the cutting efficiency can not be improved.

[0006] For achieving the object, ~~claim 1~~ a first aspect of the invention defines a ball endmill including a cylindrical tool body which is to be rotated about an axis thereof as a rotary axis, and ball-nosed end cutting edges which are provided in a distal end portion of the tool body and which describe a semi-spherical-shaped locus while the tool body is being rotated, wherein each of the ball-nosed end cutting edges has a first portion formed to extend from the axis as a starting end thereof, and a second portion formed to extend from a terminal end of the first portion as a starting end thereof, wherein the first portion has an arcuate shape which is convex forward in a direction of rotation of the tool body and which has a first radius of curvature in a distal end

view seen in a direction of the axis, the first radius of curvature being in a range of from 0.025D to 0.10D relative to an outside diameter D, and wherein the second portion has an arcuate shape which is convex forward in the direction of rotation of the tool body and which has a second radius of curvature as seen in the distal end view in the direction of the axis, the second radius of curvature being larger than the first radius of curvature.

[0007] According to ~~claim 2~~ a second aspect of the invention, in the ball endmill defined in ~~claim 1~~ the first aspect of the invention, the first portion has ~~an inscribed~~ a central angle that is in a range of from 60° to 120° as seen in the distal end view in the direction of the axis.

[0008] In the ball endmill defined in ~~claim 1~~ the first aspect of the invention, each of the ball-nosed end cutting edges includes the first and second portions having the respective first and second radii of curvature which are different in value from each other. This construction causes a cutting resistance (cutting torque) exerted by a workpiece, to ~~radially~~ act in a direction that is different in the first and second portions of each ball-nosed end cutting edge, thereby making it possible to restrain vibration of the ball endmill.

[0014] If the first radius of curvature is larger than 0.10D relative to the outside diameter D, the direction of a

line tangential to the first portion of each ball-nosed end cutting edge does not substantially vary, as in the conventional ball endmill, the direction in which the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill does not substantially vary, thereby easily causing the vibration of the ball endmill. On the other hand, in the ball endmill of the present invention in which the first radius of curvature is not larger than 0.10D relative to the outside diameter D, the direction of the line tangential to the first portion is caused to vary, so that the direction of the cutting resistance (cutting torque) can be caused to vary, thereby making it possible to restrain vibration of the ball endmill.

[0015] Further, in the case where the first radius of curvature is larger than 0.10D relative to the outside diameter D, with an axial depth of cut of the ball endmill being set to a limit value 0.1D (i.e., 10% of the outside diameter D), only the first portion of each ball-nosed end cutting edge is brought into contact with the workpiece. In this case, it is not possible to effectively enjoy the feature that causes the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill, to be different in the first and second portions of each ball-nosed end cutting edge. On the other hand, in the ball endmill of the present invention in which the first

radius of curvature is not larger than 0.10D relative to the outside diameter D, even where the axial depth of cut of the ball endmill is set to the limit value 0.1D, the second portion as well as the first portion can be brought into contact with the workpiece, thereby making it possible to effectively enjoy the feature that causes the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill, to be different in the first and second portions. Thus, the vibration of the ball endmill can be restrained.

[0020] In the ball endmill defined in ~~claim 2~~ a second aspect of the invention, in addition to the features provided by the ball endmill defined in ~~claim 1~~ the first aspect of the invention, there is a feature that the ~~inscribed~~ central angle of the first portion is in the range of from 60° to 120°. If the ~~inscribed~~ central angle is smaller than 60°, the length of the first portion of each ball-nosed end cutting edge as measured from its starting end (the axis of the ball endmill) to its terminal end (portion contiguous to the second portion) is made small, it is not possible to effectively utilize the effect that the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the first portion is caused to vary. On the other hand, in the ball endmill of the present invention in which the ~~inscribed~~ central angle is not smaller than 60°, the length of the first

portion of each ball-nosed end cutting edge can be made large sufficiently for utilizing the effect of the first portion which varies the direction of the cutting resistance (cutting torque).

[0021] If the ~~inscribed~~ central angle is larger than 120°, with an axial depth of cut of the ball endmill being set to a limit value 0.1D (i.e., 10% of the outside diameter D), only the first portion of each ball-nosed end cutting edge is brought into contact with the workpiece. In this case, it is not possible to effectively enjoy the feature that causes the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill, to be different in the first and second portions of each ball-nosed end cutting edge. On the other hand, in the ball endmill of the present invention in which the ~~inscribed~~ central angle is not larger than 120°, even where the axial depth of cut of the ball endmill is set to the limit value 0.1D, the second portion as well as the first portion can be brought into contact with the workpiece, thereby making it possible to cause the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill, to be different in the first and second portions. Thus, the vibration of the ball endmill can be restrained.

[0022]

[Fig. 1] A set of views showing a ball endmill according to an embodiment of the present invention, wherein view (a) is a front elevational view of the ball endmill, and view (b) is an enlarged side view showing in enlargement the ball endmill as seen in a direction indicated by arrow ~~Ib~~ 1(b) in view (a).

[Fig. 2] A set of schematic views schematically showing a distal end portion of the ball endmill.

[Fig. 3] A side view of a workpiece used in a cutting test.

[0023]

1 ball endmill

2 tool body

6a-6c ball-nosed end cutting edges

6a1-6c1 first portions

6a2-6c2 second portions

D outside diameter

O axis

P connection point (terminal end of first portion, starting end of second portion)

R1 first radius of curvature

R2 second radius of curvature

θ ~~inscribed~~ central angle

[0024] Hereinafter, a preferred embodiment of the present invention will be described with reference to the drawings. View (a) of Fig. 1 is a front elevational view of a ball endmill 1 according to the embodiment of the invention, and

view (b) of Fig. 1 is an enlarged side view showing in enlargement the ball endmill 1 as seen in a direction indicated by arrow ~~Ib~~ 1(b) in view (a) of Fig. 1.

[0031] In a distal end view seen in a direction (indicated by arrow ~~Ib~~ 1(b) in view (a) of Fig. 1) of the axis O of the ball endmill 1, as shown in view (b) of Fig. 1, each of the ball-nosed end cutting edges 6a-6c extends from the outer periphery to the axis O, and has an arcuate shape which is convex in a direction of rotation of the ball endmill 1 (in the counterclockwise direction as seen in view (b) of Fig. 1). The ball-nosed end cutting edges 6a-6c will be described in detail with reference to Fig. 2.

[0035] It is preferable that the first radius R1 of curvature is in a range of from 0.025D to 0.10D relative to an outside diameter D (i.e., a diameter as measured in a portion of the blade portion 3 in which ~~the diameter is maximized. In a case of a tapered endmill, however, the outside diameter D refers to a diameter as measured in an end in which the diameter is minimized~~ the ball-nosed end cutting edges 6a-6c are connected to the respective peripheral cutting edges 5a-5c, irrespective of whether each peripheral cutting edge 5a-5c is provided by a straight cutting edge or a tapered cutting edge). If the first radius R1 of curvature is smaller than 0.025D relative to the outside diameter D, a spacing gap between the first portions 6a1-6c1 of the adjacent ball-nosed

end cutting edges 6a-6c in vicinity of the axis O of the ball endmill 1 is reduced whereby performance of evacuation of cutting chips is reduced. On the other hand, in the ball endmill 1 of the present embodiment in which the first radius R1 of curvature is not smaller than 0.025D relative to the outside diameter D, the spacing gap between the first portions 6a1-6c1 can be sufficient for improving the performance of evacuation of cutting chips.

[0038] If the first radius R1 of curvature is larger than 0.10D relative to the outside diameter D, the direction of a line tangential to the first portion 6a1-6c1 of each ball-nosed end cutting edge 6a-6c does not substantially vary, as in the conventional ball endmill, the direction in which the cutting resistance (cutting torque) is exerted by the workpiece and ~~radially~~ acting on the ball endmill 1 does not substantially vary, thereby easily causing the vibration of the ball endmill 1. On the other hand, in the ball endmill 1 of the present embodiment in which the first radius R1 of curvature is not larger than 0.10D relative to the outside diameter D, the direction of the line tangential to the first portion 6a1-6c1 is caused to vary, so that the direction of the cutting resistance (cutting torque) can be caused to vary, thereby making it possible to restrain vibration of the ball endmill 1.

[0039] Further, in the case where the first radius R1 of curvature is larger than 0.10D relative to the outside diameter D, with an axial depth of cut of the ball endmill 1 being set to a limit value 0.1D (i.e., 10% of the outside diameter D), only the first portion 6a1-6c1 of each ball-nosed end cutting edge 6a-6c is brought into contact with the workpiece. In this case, it is not possible to effectively enjoy the feature that causes the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill 1, to be different in the first and second portions 6a1-6c1, 6a2-6c2 of each ball-nosed end cutting edge 6a-6c, as indicated by arrows in view (b) of Fig. 2. On the other hand, in the ball endmill 1 of the present embodiment in which the first radius R1 of curvature is not larger than 0.10D relative to the outside diameter D, where the axial depth of cut of the ball endmill 1 is set to the limit value 0.1D, the second portion 6a2-6c2 as well as the first portion 6a1-6c1 can be brought into contact with the workpiece, thereby making it possible to cause the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill 1, to be different in the first and second portions 6a1-6c1, 6a2-6c2. Thus, the vibration of the ball endmill 1 can be restrained.

[0041] Further, each of the first portions 6a1-6c1 of the respective ball-nosed end cutting edges 6a-6c is defined by ~~an inscribed~~ a central angle θ.

[0042] It is preferable that the ~~inscribed~~ central angle θ is in a range of from 60° to 120°. If the ~~inscribed~~ central angle is smaller than 60°, the length of the first portion 6a1-6c1 of each ball-nosed end cutting edge 6a-6c as measured from its starting end (the axis O of the ball endmill 1) to its terminal end (connection point P) is made small, it is not possible to effectively utilize the effect that the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the first portion 6a1-6c1 is caused to vary. On the other hand, in the ball endmill 1 of the present embodiment in which the ~~inscribed~~ central angle θ is not smaller than 60°, the length of the first portion 6a1-6c1 of each ball-nosed end cutting edge 6a-6c can be made large sufficiently for utilizing the effect of the first portion 6a1-6c1 which varies the direction of the cutting resistance (cutting torque).

[0043] If the ~~inscribed~~ central angle θ is larger than 120°, with an axial depth of cut of the ball endmill 1 being set to the limit value 0.1D (i.e., 10% of the outside diameter D), only the first portion 6a1-6c1 of each ball-nosed end cutting edge 6a-6c is brought into contact with the workpiece. In this case, it is not possible to effectively enjoy the

feature that causes the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill 1, to be different in the first and second portions 6a1-6c1, 6a2-6c2 of each ball-nosed end cutting edge 6a-6c, as indicated by arrows in view (b) of Fig. 2.

[0044] On the other hand, in the ball endmill 1 of the present embodiment in which the ~~inscribed~~ central angle θ is not larger than 120°, where the axial depth of cut of the ball endmill 1 is set to the limit value 0.1D, the second portion 6a2-6c2 as well as the first portion 6a1-6c1 can be brought into contact with the workpiece, thereby making it possible to cause the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill 1, to be different in the first and second portions 6a1-6c1, 6a2-6c2. Thus, the vibration of the ball endmill 1 can be restrained. In the present embodiment, the ~~inscribed~~ central angle θ is 90°, namely, the ~~inscribed~~ central angles θ defining the first portions 6a1-6c1 of the respective ball-nosed end cutting edges 6a-6c are all the same to each other.

[0045] The second portion 6a2-6c2 constitutes a radially outer portion of each ball-nosed end cutting edge 6a-6c, and has an arcuate shape which is convex in the rotation direction of the ball endmill 1 (in the counterclockwise direction as seen in view (a) of Fig. 2) and which has a second radius R2 of curvature. ~~The~~ A first circle C1 that is partially

constituted by the circular arc defining the first portion 6a1-6c1 is inscribed at the connection point P to a second circle C2 that is partially constituted by the circular arc defining the second portion 6a2-6c2.

[0047] Further, in the case where the second radius R2 of curvature is larger than 0.65D relative to the outside diameter D, the direction of a line tangential to the second portion 6a2-6c2 of each ball-nosed end cutting edge 6a-6c does not substantially vary, as in the conventional ball endmill, the direction in which the cutting resistance (cutting torque) is exerted by the workpiece and ~~radially~~ acts on the ball endmill 1 does not substantially vary, thereby easily causing the vibration of the ball endmill 1.

[0053] According to the result of the cutting test, in the conventional product, the direction of the cutting resistance (cutting torque) exerted by a workpiece and ~~radially~~ acting on the ball endmill was concentrated to be substantially constant, whereby the ball endmill was easily vibrated. Specifically described, in a case of cutting of the workpiece by the ball endmill for a length of time of 10 seconds, an average value of the cutting torque was 180 Nm and a variation amount of the cutting torque was 150 Nm (a maximum value of the variation amount was 230 Nm).

[0054] On the other hand, in the invention product, the cutting test revealed that the vibration of the ball endmill

1 can be restrained more than in the conventional product, since the direction of the cutting resistance (cutting torque) exerted by the workpiece and ~~radially~~ acting on the ball endmill 1 can be caused to vary. Specifically described, in a case of cutting of the workpiece by the ball endmill 1 for a length of time of 10 seconds, an average value of the cutting torque was 140 Nm and a variation amount of the cutting torque was 70 Nm (a maximum value of the variation amount was 100 Nm).

[0055] As described above, in the ball endmill 1, each of the ball-nosed end cutting edges 6a-6c includes the first and second portions 6a1-6c1, 6a2-6c2 having the respective first and second radii R1, R2 of curvature which are different in value from each other. This construction causes the cutting resistance (cutting torque) exerted by the workpiece 20 to ~~radially~~ act in the direction that differs in the first and second portions 6a1-6c1, 6a2-6c2 of each ball-nosed end cutting edge 6a-6c (see view (b) of Fig. 2), thereby making it possible to restrain vibration of the ball endmill 1.

[0062] For example, in the above-described embodiment, the ball endmill 1 is a three-flute endmill having three teeth each provided by the peripheral and ball-nosed end cutting edges 5a-5c, 6a-6c. However, the ball endmill 1 is not necessarily limited to such a detail, but may be constructed to have two teeth or four more teeth, for example. In this

case, too, as in the above-described embodiment, the direction of the cutting resistance (cutting torque) exerted by the workpiece 20 and ~~radially~~ acting on the ball endmill 1 can be varied, thereby making it possible to restrain vibration of the ball endmill 1.